MAGNETIC TEST FACILITIES AT AMES RESEARCH CENTER AND MALIBU

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Five years ago the only magnetic test coil facilities capable of testing a complete spacecraft were located on the East Coast. One was at the U.S. Naval Ordnance Laboratory at White Oak, Silver Springs, Maryland. And this is the one that we saw some pictures of in Dr. Beischer's talk. I believe we also saw some in Mr. Parsons's talk.

There is another large facility with a 20-ft coil system at the Fredricksburg Magnetic Observatory in Virginia.

In the spring of 1960, a triaxial Fanselau coil facility was erected in Corral Canyon, 3-1/2 mi north of Malibu Point, and located 30 mi north of the Los Angeles Airport. The primary purpose of this facility was to provide an environment in which the external magnetic fields of complete spacecraft could be precisely measured. Figure 1 shows a site plan of the crest of the hill on which the facilities are built.

Way in the background is the Pacific Ocean, on the left is a silo-appearing building with a vent in the top. This houses a three-axis 20-ft Fanselau coil. The Fanselau design is based on four loops in parallel and having their perimeters on the surface of a sphere. To the left of the silo is the so-called "Phase 2" OGO test building. This is an air-conditioned, nonmagnetic test house. The small structure up on the bank is the water supply, and the rather cubic structure in the right foreground is an approximately 40-ft cube building that was made of nonmagnetic construction to provide enclosure for tests in Earth's field.

Figure 2 is a close-up of the coil enclosure, to give you an idea of the scale. It is about 40 ft in diameter, and is of frame construction with plywood outside. After it was built it was necessary to guy it, because the wind loading was tilting the pad on which the foundation of the coils were supported.

Figure 3a gives you an idea of the size of the building, which was designed specifically for OGO tests in Earth's field. This building was also used to house the electronics and magnetometers.

Figure 3b is inside of this building. On the right is the OGO spacecraft, under the drape. In the floor is a gimbal that permits very precisely controlled

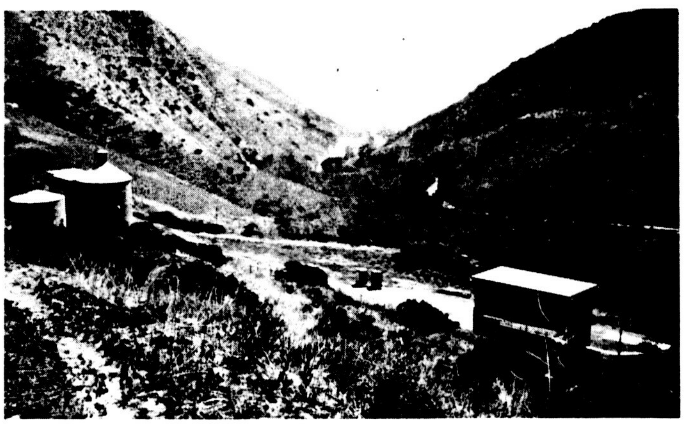


Fig. 1. NASA Malibu Magnetic Facility

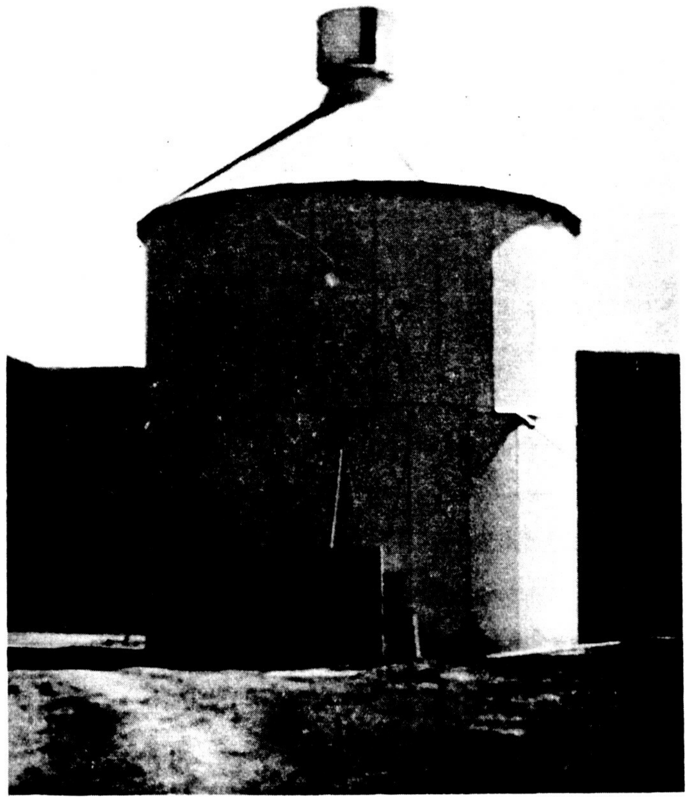
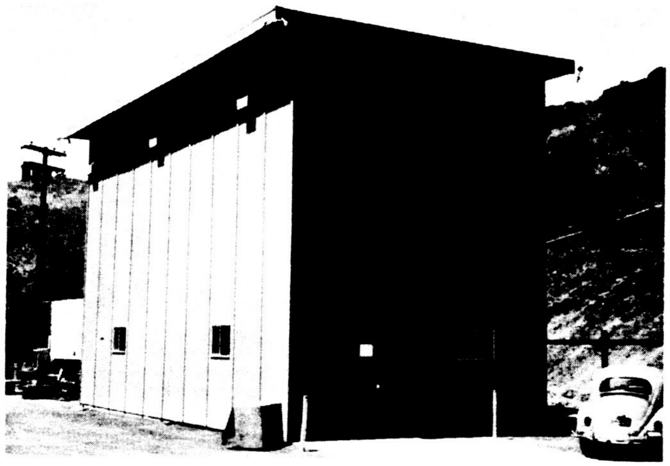
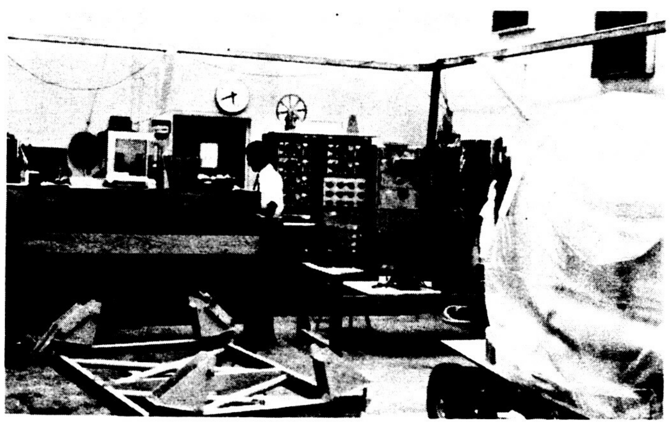


Fig. 2. Tri-axial 20-ft coil enclosure



a. Outside view



b. Inside view

Fig. 3. OGO phase I nonmagnetic building

rotation in azimuth. It has structural uprights on it with small rollers, which will receive rings that have been fixed to each end of the spacecraft ground handling equipment, so the spacecraft can be rolled about its own longitudinal axis, and it can also be rotated in azimuth.

In the background you see recorders and controls for the magnetometers. In this particular installation, the field of spacecraft is mapped in Earth's field using magnetometers at specially-determined positions, which were selected to lend themselves to evaluating the coefficients of spherical harmonic analysis without too much effort.

A computer program is then used to produce calculations of this field at any given point that was not specifically mapped.

The coil system in the silo was designed to a tolerance of approximately ±0.0005 in., using mechanical and optical techniques. The orthogonality of the coil axes are approximately 0.5 mrad. The coils are fed using stable power supplies and are capable of reducing Earth's field to zero plus or minus 1 gamma over a sphere having a diameter of approximately 3 ft.

The drift in the system is such that it can drift 1 gamma in a matter of minutes. Presently, there is no dynamic compensation because of changes in the ambient field, whether they are of geomagnetic origin or man-made.

Power consumption of the coils is such that it requires about 100 w to take care of Earth's vertical field component, and 50 w to take care of the north-south component; so that heating of the coils, because of the power supplied them, is not a factor. The coil power supplies are stable to approximately 10 parts per million. This is necessary because an error of 10 parts per million corresponds to an error in Earth's field compensation of approximately 0.5 gamma.

The noise level in the general vicinity of this site is 1 gamma, exclusive of true geomagnetic noise such as the diurnal variation or the solar storm activity.

The facility is owned and funded by NASA and is operated by the Space Technology Laboratory at Redondo Beach. The facility is in almost continuous operation in support of spacecraft contracts for the Space Technology Laboratory.

I will talk about a more modest installation at Ames. At the beginning of the Pioneer program a decision was made, by the project office, to design and build inhouse a small magnetic standards laboratory at Ames Research Center. This Center is located near the southern tip of San Francisco Bay. This laboratory is used to screen parts, train experimenter personnel, and perform magnetic acceptance tests on each of the Pioneer scientific instruments.

The first step in the development of the program was to find a site where the magnetic noise was sufficiently low. Sites in a 25-mi radius were investigated without too much luck, because of the relatively high population in the San Francisco Bay area. The best site was about 1/2 mi north of Ames Research Center in tidelands already owned by the government. This location is approximately 1/2 mi from the nearest highway, and the only road that leads to it essentially just services this facility.

The noise at the location of the facility was measured, and the frequency spectrum or power spectrum was sampled from zero to 5000 cycles. The noise was less than 0.1 gamma, except 60 cycles and harmonic frequencies thereof. At 60 cycles, we found the greatest field, and that was 2 gamma during working hours.

We might point out that we have a severe 60-cycle, 120-cycle, and 180-cycle problem, because the connected load at Ames for the centers exceeds 100 Mw. When they operate the wind tunnels, you can expect very large fields.

The enclosure for the magnetic standards laboratory was made entirely of nonmagnetic materials, so that it could be used as a region where tests could be performed in undistorted Earth's field for low gradient measurements. Aluminum nails and brass fasteners were used throughout.

The foundation is a concrete pad weighing about 32 tons. It is 1-ft thick, and it was poured continuously without reinforcement of any kind. The walls and ceiling are insulated with 4 in. of rock wool to provide thermal lagging. If you look at the coefficient of thermal expansion for aluminum, you find that it will expand something like 30 parts per million per degree. Based on a °F this means about 1 gamma change in output when you are compensating Earth's field, per °F.

Because our tests are based on a plan where measurements can be taken over a few minutes, all we need to do is prevent rapid changes in temperature, which we do by this thermal lagging. We have a thermograph in the room, and during operations we found that the heat load furnished by the electronics in the building is such that we can maintain temperature stabilities of approximately 2° F/hr.

The building outside dimensions are 15 by 30 ft. The north wall was built as a panel so that the main coil assembly could be completely assembled and aligned in the erection shop and then transported by rubber-tired crane 1/2 mi out to the laboratory.

We wanted this facility to be ready and operating by the time the first "customer" showed up. So we designed the building, the coils, and the electronics concurrently. In a matter of about 3 days, we put the coils in, closed up the wall, wheeled in the electronics, and hung out the shingle. The main coil set is composed of 12 individual square coils approximately 12 ft on a side. The basic design could be traced to Sidney Rubin's work on five-loop square coils. These coils are arranged so that the three components of Earth's field are mutually coaxial with the coil set axes. What this means is that when they laid the forms for the pad, we had them lay the long axis of the building, parallel to the local magnetic meridian, within 3 min of arc; so that one axis of the coil could essentially take care of 99.9% of the Earth's horizontal component. The residual error we can take care of by a simple Helmholtz coil oriented in an east-west direction. The success of this was demonstrated on several occasions where we have had to change the polarity of the correction we make for the east-west effect.

It is unlikely that the building is rotating, so we are assuming that the direction of the magnetic meridian is swinging on both sides of the axis of our building. Each axis is individually driven, using the current supply stable to 0.001%. Spacing of the coils and number of turns have been designed to produce fields having a maximum volume of uniformity.

We took Mr. Rubin's design one step farther so we would get a more spherical shape volume of uniformity. His original design produced a more right circular cylindrical type volume of uniformity where the length to diameter was not unity.

As far as performance goes, the system permits an attenuation of Earth's field by a factor of 10,000 over a volume of 1 ft^3, and by a factor of 1000 over 1 yd^3. The field measurements capabilities of the lab are in the range of 1 to 30 kilogauss AC or DC ±2%, and in the range of zero to 1 gauss DC, ±0.02% ±0.2 gamma, whichever is greater.

Inside the main coil set is a high field Helmholtz pair capable of producing a 30-gauss field for perming and deperming. This coil has a diameter of 4 ft.

The advantage of rectangular coils is that they blend right into the walls of the room and provide a very free working area for manipulating samples. The test area is about 6 ft off the pad, so we had a little nonmagnetic platform to make it more convenient to operate the gimbal. The Helmholtz coil is 4 ft in diameter, and it is oriented vertically. Coaxial with it is a gimbal system that permits rotation in azimuth and rotation in inclination.

The readout is by means of a magnetometer, which is in a little device suspended from a trolley overhead. A pipe coming down supports the magnetometer, which can be oriented radially or in the other two axes. Normally, it is positioned radially. By moving back and forth on the trolley, we can take measurements at various ranges from the sample. This shaft extends into a concrete block, weighing 300 lb, that is hollow and terminates in a 10-turn trim potentiometer which is used as a voltage divider to move the one axis of an X-Y plotter; the output of the magnetometer moves the other axis, so we have a $10 servosystem used to actually plot azimuth position versus field intensity.

Exclusive of electronics, the building and the coils cost approximately $20,000. It was built in approximately 120 days, using noncrash type funding and no overtime.

All the electronics are essentially commercial manufacture, which resulted from rather extensive market surveys. Figure 4 gives a little more detail of the gimbal.

It is a very simple gimbal. The width of the vertical member is 2 in. As I recall, it is approximately 1-in. plate. It was made of 6061 aluminum, and it cost less than $400. Because we rotate about the cg, we have counterweights and a little jack screw just under the little table in the center so we can position the sample on the gimbal and keep it in balance. So, actually we can now clamp the specimen to the table, which is made of plywood, by proper mounting hardware — we can set it by hand on this and check to see if the gimbal starts to move because of imbalanced moments. We can just move the footprint of the specimen on our table top until this imbalance ceases to exist, in which case we now are positioned so the cg is in center of balance of the gimbal. The round table will slip, and has a friction clutch at the top of the jack screw so, if we wish to incline the sample or map in any vertical plane (which would be like a great circle through a longitudinal line), we can rotate the specimen on this table until that plane of rotation is normal to the little trunion axis.

Since this photograph was taken we have quite precise setting circles on all the axes, because we found that you can't do precise work unless you can orient your sample to 1 deg or better.

All the electronics for the system are mounted in a wooden console we designed and built ourselves, and they are mounted on casters so in a very short

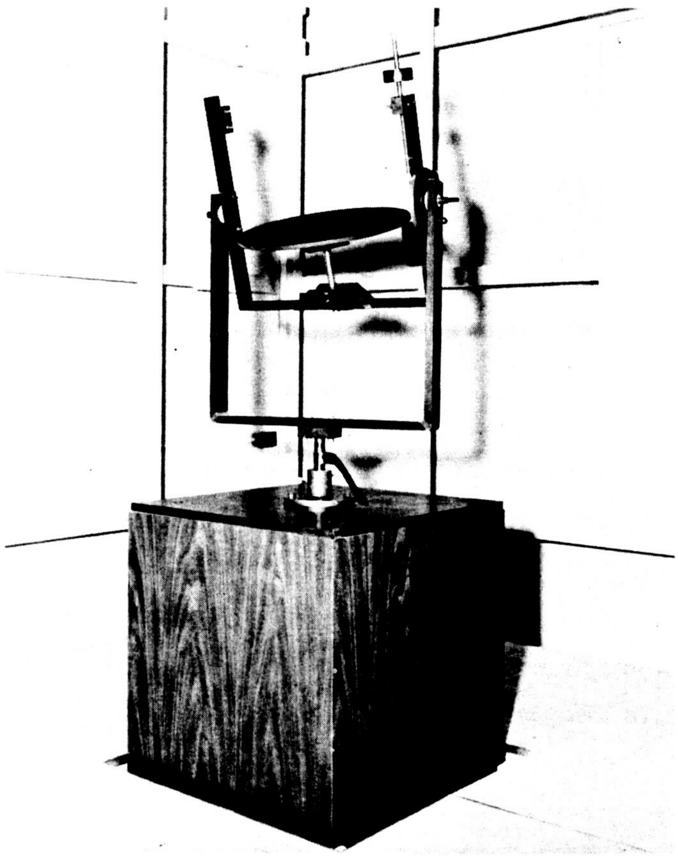


Fig. 4. Gimbal system for magnetic mapping

time we can wheel all of the magnetic material away from the building and work on extension cables. We have found that we can tolerate some 300 lb of electronics 15 ft away from the coil center, and make measurements reproducible to 0.1 gamma. If anybody moves anything, we can be off many gamma, but (as long as the material is stationary), we find that the gradient produced by a rack of electronics does not interfere with our measurements.

In tomorrow's paper, I will discuss some of the performance requirements based on the measurements for which this facility was designed.

OPEN DISCUSSION

MR. FRANDSEN: I have a question on the supporting of the nonstandard shaped assemblies, such as protrusions or experiments or something that isn't in a nice box. How do you support this by clamping without possibly damaging something or damaging a gold surface?

MR. IUFER: I seem to be coming reluctant about pointing out advantages Pioneer has. For the experiments — each one has a flat mounting surface that mounts to the instrument shelf. We use this. If someone wants a subassembly, which may be a mother board with modules on both sides of it, measured. This same individual takes off his belt and his watch and his glasses, and becomes nonmagnetic, and manipulates the sample in the test area. We don't handle it. He knows what can be stressed and what can't.

Some of the support tricks we have used have been masking tape, blocks of wood, ordinary molding clay, scotch tape (with these sort of things we were able to obtain the stabilities necessary) to actually anchor it in position.

MR. FRANDSEN: I wonder if Mr. Parsons could possibly say something about the way they clamp theirs. This really has been a bugaboo to us because of the gold surfaces and odd shapes.

MR. PARSONS: We use a gimbal very similar to Mr. Iufer's here, except it is a little heavier. As a matter of fact, we have two; one is designed for the smaller packages of the type we got from the IMP spacecraft program, and the other is a larger set of identical equipment for the bigger components. The IMP package is roughly 9 in., it is the number limit for its dimension; for the OGO, we can go up to

16 or 18 in. What we have is a pair of plates inside our gimbal box that are adjustable toward each other by a system of lead screws. These are padded with a 1/4 in. rubber pad. We bring the package in; the experimenter, or whoever is responsible for it, is always with it. We show him how we plan to mount, and he decides "yea" or "nay" on the mechanical stressing of this thing.

Normally, we have had no problem on this at all, and the point was raised back there before, so I am trying to be a little cautious – but actually we haven't had any trouble on this. We put the package in the concentric circles inscribed on these rubber pads, place it in there, and clamp it down. The man who clamps, of course, is experienced in this. He doesn't mash the thing flat, but he gets enough grip on it so it won't fall out. The only hazard that we ever had was in the early days when we were a little too cautious with one package; we didn't squeeze it quite tight enough, and it did fall out. This does disturb the experimenter no end.

Since that time, we have taken several precautions. We have foam padding on the floor below. We have restraining elastic bands on our boxes now; so, even if the package would come loose, it would slide only to the edge of the shelf and then be restrained by elastic bands. This takes care of 90% of our problems. Occasionally we get an oddball device that won't lend itself to this kind of mounting. So, then you have to build a little fixture especially for that purpose. We have several of these now that are made of plywood sections, etc. with nonmagnetic bolts, etc. We can mount almost anything, but to do it most rapidly and conveniently, the squeeze method has worked the best for us.

MR. BROOK: We are now having a problem with one of our experimenters. I believe he is from Goddard and there is a problem of magnetic materials. The question of an oddball shape. You handle 90%; well, I have the other 10%.

It is something like a 100 in. X-ray telescope, which may or may not be made of magnetic materials. These are being investigated now. I think that Mr. Parsons will probably be stuck with the problem of checking it out.

Do you care to comment on that?

MR. PARSONS: Well, we take on all comers. We don't guarantee results, but I have looked over one preliminary early model that I think, of a similar scope, was associated with one of the programs. It is going to be a problem, all right. So that is what we live on – problems. We will fixture it as necessary. Hopefully, by the time this thing gets to us, we may have some of our newer facilities ready. We will have a larger volume in which to work and move. We will have some more sophisticated fixturing, which we are trying to get designed now. We will cope with the problem.

MR. IUFER: On this telescope, you might consider having a magnetic specification on the transit case and just leaving it in it.

MR. CHRISTY: Just a comment on that. We have done this in some cases on Mariner Mars. The handling frames were made out of A-286 and titanium and a few cold-rolled bolts. But we replaced the hard steel stuff, particularly for the communications packages where they are extremely fussy, and rightly so. We did use this sort of technique and it is quite satisfactory.

MR. IUFER: Be sure and have the man demonstrate that; it is really in the transit case when you measure it.